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5Gyres



Informational Document for Stakeholders and Legislators on Potential Microbead Legislation

"Biodegradable" plastic microbeads should not be exempt.

- **"Biodegradable" is a misleading claim** (all things break down given enough time) that has been abused by marketers and investigated by the U.S. Federal Trade Commission for violation of their Green Guidelines.ⁱ In fact, there is currently no working ASTM International standard specification for biodegradable plastics in the marine environment.ⁱⁱ Such plastics tend not to actually biodegrade into benign substances but instead break down into smaller pieces that exacerbate the plastic pollution problem.
- If a product does in fact biodegrade in a marine environment, it does so over six months or more. Consequently it persists in the aquatic environment and remains **bioavailable to wildlife who mistake it for food.**
- Both bio- and traditional plastics attract hydrophobic pollutants. **While in the environment all plastic, regardless of its degradability, absorbs toxins,** collecting and contaminating the environment or concentrating them up the food chain. Therefore, safe alternatives **must be inert to the ecosystem before they leave the wastewater treatment system and enter the water.**
- The **current data establishing the long half-life of "marine-degradable" plastics** means they still **pose a threat to marine life that consume them,** from zooplankton on up the entire aquatic food chain. Studies find that **toxic chemicals in or absorbed onto the micro plastic particles leach into the tissues** of aquatic organisms, increasing the concentration of pollutants in seafood that may be consumed by people.ⁱⁱⁱ
- "Biodegradable" plastics, just like traditional plastics, **contain chemical additives** that may be unknown and unsafe.

Preemption of local ordinances should not be included.

- Preemption language supported by industry would prevent effective local initiatives and would garner unwanted opposition from local governments and their allies.

Please see the attached model legislation for more information.

Additional Reading and Resources

Long Term Field Measurement of Organic Contaminants to Five Types Of Plastic Pellets

Ingested Plastic Transfers Hazardous Chemicals To Fish And induces Hepatic Stress

<http://www.culturechange.org/cms/content/view/856/1/>

CalRecycle Report on "PLA and PHA Biodegradation in the Marine Environment"

<http://www.resodema.org/publications/publication17.pdf>

ⁱFTC Cracks Down on Misleading and Unsubstantiated Environmental Marketing Claims. Press Release, Oct. 2013.

<http://www.ftc.gov/news-events/press-releases/2013/10/ftc-cracks-down-misleading-unsubstantiated-environmental>

ⁱⁱASTM Standard Specification D7081 Standard Specification for Non-Floating Biodegradable Plastics in the Marine Environment.

<http://www.astm.org/Standards/D7081.htm>

ⁱⁱⁱ Marine Plastic Pollution and Seafood Safety. Feb. 2015. Volume 123, Number 2. <http://ehp.niehs.nih.gov/123-A34/>



Scientific Evidence Supports a Ban on Microbeads

Growing scientific evidence indicates that synthetic plastic microbeads (hereafter, microbeads) are a threat to the environment and should be banned from all personal care products. Microbeads pollute the environment, adding to the increasing abundance of microplastic debris. Too small to be efficiently filtered by wastewater treatment processes, microbeads are found in aquatic habitats and fish. Microplastic debris, and its inherent cocktail of chemical pollutants, has been found in the stomachs of hundreds of species of wildlife. The ingestion of microplastic may cause bioaccumulation of hazardous chemicals and adverse health effects in wildlife and people.

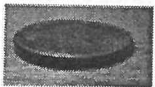
Background on the bead

Microbeads are a form of microplastic¹. Thus, scientific evidence related to the sources, fate and effects of microplastic inform our understanding of microbeads. In particular, microbeads are fragments or beads of plastic, ranging from roughly 5µm to 1mm in size and do not biodegrade in nature. Microbeads are used in hundreds of products including cosmetics, sunscreen, body wash, toothpaste, skincare, and industrial and household cleaning products¹⁻³. They are used for several reasons, including as cleansing materials or exfoliants (often replacing naturally biodegradable alternatives) to hide wrinkle lines in cosmetics and to improve the feel of formulated products such as lotions.

What's the problem?

Microbeads are found in aquatic habitats^{4,5} and in wildlife⁶ adding to the growing quantities of microplastic debris. Microbeads, like all microplastic, have the potential to contaminate food chains³, including seafood products consumed by people. Microbeads in personal care products are designed to be discarded down the drain during normal use^{1,3,7}. Due to their small size, it is not feasible for wastewater treatment plants to screen microbeads, which are then littered via final effluent or sewage sludge into the environment⁸.

TINY BEADS- BIG PROBLEM



5.8 microbeads
would fit across the
edge of a penny

Policy Recommendations:

1. State and federal legislation should ban synthetic plastic microbeads from all personal care products, including "over the counter drugs" and cosmetics.
2. Legislation should define "synthetic plastic microbeads" as any intentionally added synthetic plastic particle that escapes wastewater treatment processes and is not marine biodegradable, and thus is bioavailable to wildlife.



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We support legislation banning microbeads from personal care products, a position supported by the weight of scientific evidence regarding the fate, persistence and toxicity of microplastic debris.



Microbead contamination and harm

Although their small size makes them difficult to detect, microbeads have been found in inland and coastal aquatic habitats^{4,5} and in fish⁶. Experiments have demonstrated harm in fish^{9,10} from plastics that are the same type, size and shape as common microbeads.

Microbeads pass through water treatment facilities, are released into natural waterways and become microplastic debris. Microplastic is ubiquitous in aquatic habitats, including bays^{11,12}, estuaries and shorelines^{13,14}, coral reefs¹⁵, the deep-sea¹⁵, freshwater lakes¹⁶, rivers⁵ and Arctic Sea ice¹⁷. Microplastics persist in aquatic and terrestrial habitats for decades where they accumulate hazardous chemicals. Microplastic has been reported in hundreds of species globally, including marine mammals, turtles, seabirds, fish and invertebrates¹⁸. Microplastics cause physical and chemical harm to animals^{9,19}. Physically, microplastic can cause cellular necrosis, inflammation and lacerations in the digestive tract²⁰. Chemically, microplastic is associated with a complex mixture of chemicals, many of which are priority pollutants under the US EPA Clean Water Act for being persistent, bioaccumulative and/or toxic²¹. Chemicals associated with this 'cocktail' can accumulate in animals that eat them^{9,10,19,22-27} and cause liver toxicity and disrupt the endocrine system^{9,10}.

Current Progress

62 NGOs from 31 countries support the ban.

Multinational companies, including Unilever, L'Oreal, Procter and Gamble and Johnson & Johnson, have pledged to stop the use or sale of microbeads.

Bans have been proposed federally and in many states, including AK, CA, CT, CO, HI, IA, IN, MD, ME, MI, MN, NJ, NY, OH, VA, VT, WA, WI, & WY.

IL passed a ban on microbeads.

Illinois Microbead-free Waters Act

This legislation contains loopholes allowing continued production and use of microbeads that escape wastewater treatment processes and are not biodegradable in the aquatic environment.

Text From the Bill:

"Plastic" means a synthetic material made from linking monomers through a chemical reaction to create an organic polymer chain that can be molded or extruded at high heat into various solid forms retaining their defined shapes during life cycle and after disposal.

Loophole: Defining plastic as those molded at high heat, linking monomers, and retaining their defined shapes after disposal, allows for plastics that degrade **slightly** in an unspecified time period.

Text From the Bill:

"Synthetic plastic microbead" means any intentionally added non-biodegradable solid plastic particle measured less than 5 millimeters in size and is used to exfoliate or cleanse in a rinse-off product.

Loophole: "Biodegradable" is not defined in terms of % degradation under a specified time frame in the environment, allowing microbeads to be made from plastics like PLA—a material that is not marine biodegradable²⁸.

In the San Francisco Bay Estuary,

BILLIONS OF MICROBEADS
are washed down household drains
EVERY DAY.

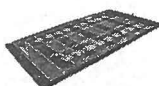
California's state-of-the-art Waste Water Treatment Plants cannot feasibly filter out these small particles.

OVER 471 MILLION MICROBEADS

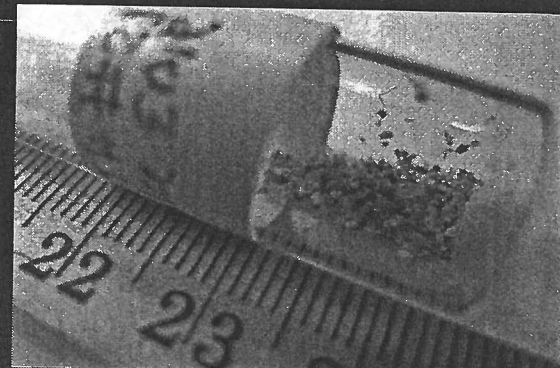
are directly released into San Francisco Bay **every day** via final effluent



The microbeads directly released into San Francisco Bay each year would cover over 1 and a half football fields



Calculations are based upon average estimates of microbeads reported in final effluent^{8,6,29}, estimates that 99% of microbeads that enter waste water treatment plants are retained in sewage sludge⁸ and the total flow of 35 waste water treatment outfalls that release effluent into the San Francisco Bay/Estuary³⁰. *It is noteworthy that this capture does not mean it is not released into the environment. Oftentimes sludge is land-applied in agricultural fields and terrestrial environments.*



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Resolution—

Whereas, microbeads in personal care products are indistinguishable from litter and cause the same problems as microplastic debris; and

Whereas, the weight of the scientific evidence regarding the fate and hazards of microplastics leans heavily in support of the ban on microbeads; and

Whereas, microbeads qualify as pollution and therefore should be regulated under existing U.S. legislation, such as the Clean Water Act; and

Whereas, a clean environment free of pollutants supports healthy populations of wildlife and safe seafood and clean waterways for people; now, therefore,

We support legislation banning microbeads from personal care products, a position supported by the weight of scientific evidence regarding the fate, persistence and toxicity of microplastic debris.

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References: 1. Browne, M. A., et al. (2007). *IEAM*, 3(4), 559-561. 2. Gregory, M. R. (1996). *Mar Pollut Bull*, 32(12), 867-871. 3. Fendall, L. S., & Sewell, M. A. (2009). *Mar Pollut Bull*, 58(8), 1225-1228. 4. Eriksen, M., et al. (2013) *Mar Pollut Bull*, 77(1), 177-182. 5. Castañeda, R. A., et al. (2014). *Can J Fisheries and Aquatic Sci*, 71(12), 1767-1771. 7. Zitko, V., Hanlon, M. *Mar Pollut Bull* 22, 41-42 (1991). 8. Magnusson, K., Noren, F. (2014). IVL Swedish Environmental Research Institute. 6. Mason, S., unpublished work. 9. Rochman, C. M., et al. (2013). *Sci Rep*, 3. 10. Rochman, C. M., et al. (2014b). *Sci Tot Environ*, 476, 622-633. 11. Endo, S., et al. (2005). *Mar Pollut Bull*, 50(10), 1103-1114. 12. Ashton, K., et al. (2010). *Mar Pollut Bull*, 60(11), 2050-2055. 13. Browne, M. A., et al. (2011) *Environ Sci & Technol*, 45, 9175-9179. 14. Browne, M. A., et al. (2010). *Environ Sci Technol*, 44(9), 3404-3409. 15. Woodall, L. C., et al. (2015). *Front Mar Sci*, 2(3). 16. Zbyszewski, M., & Corcoran, P. L. (2011). *Water Air Soil Pollut*, 220(1-4), 365-372. 17. Obbard, R. W., et al. (2014). *Earth's Fut*, 2(6), 315-320. 18. Gall, S., Thompson, R. C. (2015) *Mar Pollut Bull*. In press. 19. Browne, M. A., et al. (2013). *Curr Biol*, 23(23), 2388-2392. 20. Rochman, C.M., et al. *Ecology*. In review. 21. Rochman C. M., et al. (2013) *Nature*, 494, 169-171. 22. Teuten, E. L., et al. (2009) *Phil Trans Roy Soc B* 364, 2027-2045. 23. Tanaka, K., et al. (2013) *Mar Pollut Bull* 69, 219-222 (2013). 24. Gaylor, M. O., et al. (2012). *Chemosphere*, 86(5), 500-505. 25. Lavers, J. L., et al. (2014). *Environ Pollut*, 187, 124-129. 26. Besseling, E., et al. (2013) *Environ Sci & Technol*, 47, 593-600. 27. Chua, EM et al. (2014) *Environ Sci Technol* 38, 8127-8134. 28. CalRecycle (2012) Department of Resources Recycling and Recovery. Publication #DRRR-2012-1435. 29. CA Regional Water Quality Control Board (2011) SF Bay Basin Water Quality Control Plan (Basin Plan). 30. Martin, C., Eizhvertina, O. (2014). Niagara College Environmental Technician-Field and Lab (co-op): Final Term Research Project.



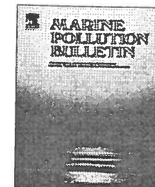
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Microplastic pollution in the surface waters of the Laurentian Great Lakes

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ABSTRACT

Neuston samples were collected at 21 stations during an ~700 nautical mile (~1300 km) expedition in July 2012 in the Laurentian Great Lakes of the United States using a 333 μ m mesh manta trawl and analyzed for plastic debris. Although the average abundance was approximately 43,000 microplastic particles/km², station 20, downstream from two major cities, contained over 466,000 particles/km², greater than all other stations combined. SEM analysis determined nearly 20% of particles less than 1 mm, which were initially identified as microplastic by visual observation, were aluminum silicate from coal ash. Many microplastic particles were multi-colored spheres, which were compared to, and are suspected to be, microbeads from consumer products containing microplastic particles of similar size, shape, texture and composition. The presence of microplastics and coal ash in these surface samples, which were most abundant where lake currents converge, are likely from nearby urban effluent and coal burning power plants.

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1. Introduction

Plastic pollution is the dominant type of anthropogenic debris found throughout the marine environment (Barnes et al., 2009; Gregory and Ryan, 1997). Floating plastic debris, including microplastics, have been reported in the subtropical gyres since the early 1970s in the North Atlantic (Carpenter and Smith, 1972; Colton et al., 1974; Law et al., 2010), North Pacific (Day et al., 1990; Moore et al., 2001), South Pacific (Eriksen et al., 2013), and outside the subtropical gyres in near shore environments (Thompson et al., 2004; Thiel et al., 2013; Dubaish and Liebezeit, 2013).

These plastic debris can be found in high densities and can have far ranging impact on marine ecosystems. Though other types of debris are found in the marine environment, such as glass floats,

bottles and light tubes, metal cans and derelict traps, and nets and line, 60–80% is estimated to be petroleum-based plastic (Derraik, 2002; Thompson et al., 2004; Browne et al., 2010, 2011). Plastic marine pollution has the potential to transport non-native species beyond their historical geographic range (Astudillo et al., 2009; Barnes and Fraser, 2003; Bravo et al., 2011; Gregory, 2009; Webb et al., 2009). A wide range of marine life are impacted by plastic pollution through entanglement or ingestion, including marine mammals, birds and reptiles (Laist, 1987; van Franeker et al., 2011), as well as through the persistent organic pollutants that sorb onto the plastic (Mato et al., 2001; Teuten et al., 2007, 2009; Rios et al., 2010). The Convention on Biological Diversity summarized there are currently 663 species of marine life that are known to be impacted by marine debris (Convention on Biological Diversity, 2012).

Plastic pollution may enter waterways through drainage systems, sewage treatment overflow during high-volume rain events (EPA, 2007; Browne et al., 2010; Browne et al., 2011), or can blow off beaches or developed structures, like docks and piers (Ryan et al., 2009). Microplastics may form on land by UV degradation and fragmentation (Andrady, 2003; Thompson et al., 2004; Cole et al., 2011) or road abrasion of larger plastic items through damage by vehicles and transport along concrete pathways, but may also enter the aquatic environment through direct release (Browne

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et al., 2010). Polyethylene and polypropylene microbeads, used in many consumer facial cleansers, have been identified as potential contributors to marine pollution (Gregory, 1996; Fendall and Sewell, 2009). Textile laundering facilities are also potential sources of microplastic fibers (Browne et al., 2011), and microplastic particles from sandblasting media have been suspected to pollute the marine environment since the early 1990s (Zitko and Hanlon, 1991).

Despite the ubiquitous nature of plastic pollution within the open-waters of the world's oceans, data describing microplastic abundance in the Laurentian Great Lakes has been limited to beach surveys (Zbyszewski and Corcoran, 2011). Given that the watersheds surrounding the Great Lakes are heavily urbanized (including the cities of Chicago, Milwaukee, Detroit, Cleveland and Buffalo in the United States, and Toronto in Canada), flow into the St. Lawrence River and ultimately to the North Atlantic Ocean, the lakes represent an important, potential upstream source of plastic pollution into the North Atlantic Gyre. We report here the first open-water survey for plastic pollution within the Laurentian Great Lakes system.

2. Materials and methods

To explore the presence and distribution of plastic pollution in the Laurentian Great Lakes, an expedition aboard the U.S. Brig Niagara was jointly organized between the 5 Gyres Institute⁶ and SUNY Fredonia. The 3-week expedition began on 11 July 2012 from Munising, Michigan, sailed Lakes Superior, Huron and Erie before ending on 31 July 2012 in Erie, Pennsylvania. Five samples were collected in Lake Superior, while 8 samples each were collected in lakes Huron and Erie. The sea state on the Beaufort Scale remained between 1 and 3 for all sample sites. The 21 sample sites were not equidistant, but samples were each 60 min long, timed using a stopwatch, and the tow speed was kept to 2.0 knots. All samples were preserved with 70% isopropyl alcohol.

Samples were collected using a manta trawl with a rectangular opening 16 cm high by 61 cm wide, and a 3 m long 333 μ m net with a 30 \times 10 cm² collecting bag. The net was towed along the surface on the downwind side of the vessel using a spinnaker pole to position the towline outside of the ship's wake. The area sampled was calculated by using the onboard knotmeter, which measures the number of nautical miles traveled over a defined distance, to measure the actual length of sea surface trawled in the 60-min period. The tow length multiplied by the width of the trawl provided the area sampled, allowing particle abundance per square kilometer to be calculated.

The samples were later rinsed in salt water, which floated most of the plastic to the surface for removal. Using a dissecting microscope, plastic was removed from preserved natural material, and then sorted by rinsing through Tyler sieves into 3 size classes: 0.355–0.999 mm, 1.00–4.749 mm, >4.75 mm. Individual pieces of plastic were divided into categories; fragment, foamed polystyrene, line, pellet, film; and then counted.

To understand the surface characteristics and chemical composition of the micro-particles initially sieved from the Great Lakes samples, all particles within the 0.355–0.999 mm size class for each of the 21 samples were examined using scanning electron microscopy (SEM). Samples were spread on double-sided carbon tape, coated with a thin film of evaporated carbon, and then imaged using a Hitachi SU70 field emission SEM operating at 20 keV in backscatter mode. Qualitative elemental composition of particles was confirmed using an Oxford INCA Energy Dispersive X-ray Spectroscopy system (EDS). As SEM analysis showed the development of very healthy biofilms on the surface of collected

particles a small fraction of sample 21 was soaked in 2 M hydrochloric acid for a period of 24 h, sieved, rinsed with deionized water and dried prior to SEM analysis in order to image particle surfaces in absence of this biofouling.

3. Results

Of the 21 net tows, all samples except one, sample 13, contained plastic (Fig. 1, Table 1). The initial visual analysis separated natural debris from material suspected to be plastic. The SEM/EDS system was used for microscopic and elemental analysis of particles from all samples <1 mm. Particles >1 mm were more easily identified as plastic, and therefore excluded from SEM/EDS analysis.

Several particles <1 mm were suspected to be paint from the vessel based on the red color and laminate nature. SEM/EDS analyses confirmed that suspected paint fragments were not polymeric and had a nearly identical elemental fingerprint to samples taken from the vessel. It was concluded that these were paint chips from the vessel and they were excluded from plastic particle counts.

SEM/EDS analysis also allowed the determination that many particles initially identified as microplastic were actually aluminum silicates. The aluminum silicate particles were determined to be coal ash and coal fly ash (Fig. 2) based upon a match between our SEM/EDS analysis and similar analyses performed by a commercial ash analysis firm (STS Analytical Testing Laboratory). Of our 21 samples, 8 were found to contain coal/fly ash, with an average contribution of 20% (within the 0.355–1 mm size classification). Our two samples with high particle counts, sample 20 & 21, contained 28% and 27% aluminum silicate, respectively, showing that visual observation alone is insufficient to separate microplastic from other debris.

Natural fibers, aluminum silicate particles and paint fragments were removed from all visually sorted samples. The adjusted microplastic abundance for all samples is given in Table 1. While the samples showed great spatial variability (Fig. 1), with particle counts ranging from ~450 up to over 450,000 per square kilometer, the samples from Lake Erie were consistently the most concentrated as compared to the other two Great Lakes sampled. In fact, Lake Erie samples account for ~90% of all the pelagic plastic debris, with samples 20 and 21 alone containing 85% of all microplastic particles collected in all samples combined. Lake Superior

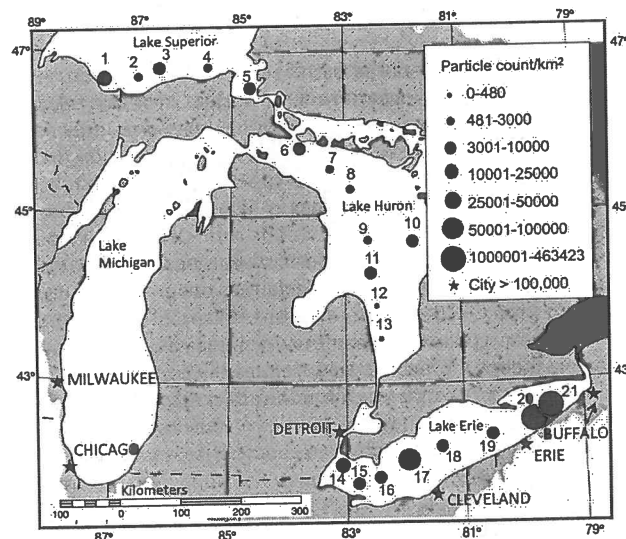


Fig. 1. Distribution of plastic particles by count for 21 samples collected in three of the Laurentian Great Lakes.

⁶ <http://www.5gyres.org>.

Table 1

Count, location and abundance of plastic pollution from 21 stations in three of the Laurentian Great Lakes.

Count, location and abundance of plastic pollution in the Great Lakes					
Sample id.	Latitude	Longitude	Count total	Tow length (km)	Abundance (count/km ²)
<i>Lake Superior</i>					
1	46.5737	–87.3413	15	1.94	12,645
2	46.6872	–86.6649	8	3.70	3541
3	46.7772	–86.4405	3	3.85	1277
4	46.8487	–85.2473	6	3.76	2616
5	46.5860	–84.7222	16	3.82	6875
<i>Lake Huron</i>					
6	45.8682	–83.7218	11	3.80	4750
7	45.6372	–83.3776	3	4.00	1229
8	45.3463	–83.0087	4	3.87	1694
9	44.7287	–82.5399	5	3.70	2213
10	44.7676	–81.9475	15	3.76	6541
11	44.3480	–82.5583	13	3.98	5352
12	43.9240	–82.5130	1	3.59	456
13	43.4134	–82.3994	0	3.93	0
<i>Lake Erie</i>					
14	41.8979	–83.0498	26	3.78	11,282
15	41.7523	–82.9450	9	3.15	4686
16	41.7830	–82.7569	20	3.85	8511
17	41.8953	–82.3409	131	3.76	57,122
18	42.1425	–81.5131	13	3.52	6056
19	42.2441	–80.7501	21	3.78	9112
20	42.3938	–79.9536	1101	3.87	466305
21	42.3000	–80.0259	657	3.83	280947

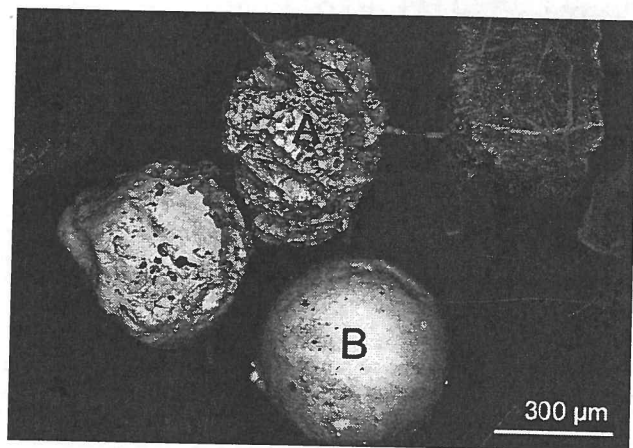


Fig. 2. Coal ash (A) has an irregular surface, whereas coal fly ash (B) does not. Particle B was initially identified as microplastic until SEM/EDS confirmed its inorganic composition.

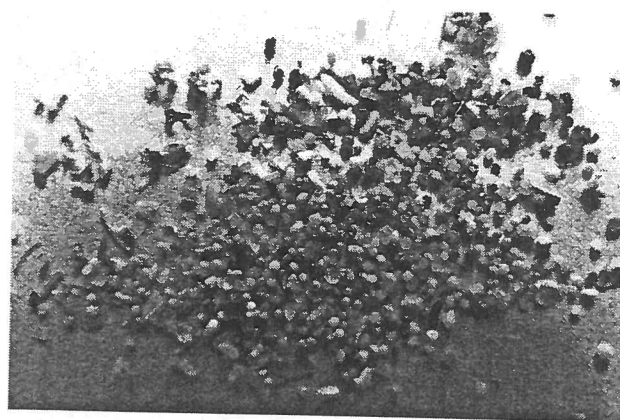


Fig. 3. Color variation among particles <1 mm from Sample 21.

Table 2

Abundance and type of particles in three size classes.

	Abundance of plastic particles (count/km ²) by type and size		
	0.355–0.999 mm	1.000–4.749 mm	>4.75 mm
Fragment	247,106.5	123,906.2	11,219.8
Film	3943.5	1332.2	4006.1
Foam	54,340.9	18,208.4	1810.5
Pellet	430,029.8	5614.1	420.9
Line	1328.9	2571.9	449.0
Count/km ²	736,749.6	151,632.9	17,906.3
% Of total	81%	17%	2%

tended to show slightly higher particle counts as compared to Lake Huron.

After adjusting particle counts for all 21 samples from the Great Lakes after SEM/EDS analysis, the average abundance was 43,157 plastic particles/km². Table 2 shows the distribution of particles

within each of the three size classes, and each of the 5 type categories. Microplastic pellets and fragments were far more abundant than other particle types. The size classes representing particles 0.355–0.999 mm accounted for 81% of the total particle count. Great Lakes sample 20, collected at 42°23.62N, 79°57.21W, contained 1101 plastic particles, or 463,423 particles/km², which was the highest count in one 60-min tow and greater than the count of all other samples combined. Several microplastic particles in these samples were green, blue and purple colored spheres, which were suspected to be microbeads from consumer products (Fig. 3).

Two national brands of facial cleansers containing polyethylene microbeads were sieved and analyzed using the SEM/EDS system to evaluate their texture and composition. The microbeads within these consumer products were compared to the multi-colored microplastic spheres in the samples, and found to be of similar shape, size, color and elemental composition (Fig. 4).

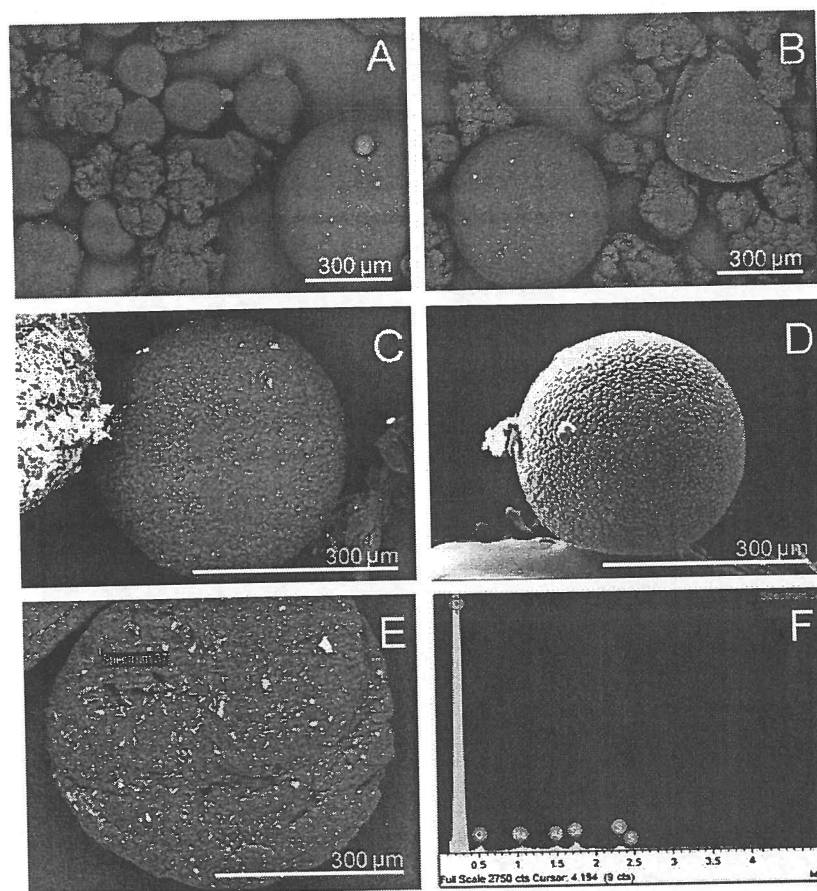


Fig. 4. (A) SEM image of product 1 containing polyethylene microbeads. (B) Polyethylene microbeads in product 2. (C & D) SEM image of spherical fragment from GL 21 after HCl wash. (E) SEM image of blue spherical fragment from GL 21. (F) Elemental analysis of fragment E showing it to be polymeric material.

4. Discussion

The results of this study posed several questions about the source of microdebris, including the identity of microplastic particles. Many coal and fly ash particles were found. In the 8 states that border the Great Lakes, there are 144 coal-burning power plants (Stamper et al., 2012), which may release aluminum silicates in the form of coal ash or fly ash into waterways through wastewater discharge or aeolian transport. These inorganic microdebris were removed from the samples, leaving abundant microplastic particles with physical characteristics similar to microbeads used in two primary commercial applications: sandblasting media and abrasives in consumer products.

Sandblasting media using polymeric materials include acrylic, with a density of 1.19 g/cm^3 , polystyrene (1.05 g/cm^3), melamine (1.51 g/cm^3), thermoset polyester polymer (1.5 g/cm^3), poly allyl diglycol carbonate (1.31 g/cm^3), amino thermoset plastic ($1.47\text{--}1.52 \text{ g/cm}^3$) and urea (1.50 g/cm^3). All of these materials would be negatively buoyant in freshwater, and therefore are not likely to appear within samples obtained in the Great Lakes.

Multi-colored spherical particles in the size class $<1 \text{ mm}$ (Fig. 3) may be linked to consumer products. Some facial cleansers, and other personal care products, contain spherical microbeads labeled on the product as polyethylene ($0.91\text{--}0.96 \text{ g/cm}^3$) or polypropylene (0.91 g/cm^3), which would float in freshwater systems. Once used by the consumer, the plastic microbeads may be washed down the drain, but few, if any, wastewater treatment facilities capture all floating, non-biodegradable particulate

of 0.5 mm size or smaller. Sewage sludge, which may contain microbeads, is often used as fertilizer in agriculture and public lands (Saruhan et al., 2010). Also, during high rain events some municipalities, which have combined sewer systems, may experience combined sewage overflow (CSO) events allowing raw sewage to enter local waterways untreated (EPA, 2007). Hence, there are multiple point sources where microbeads may enter the marine environment.

There are a number of factors that may contribute to the large spatial variability of plastic pollution in our samples. Of the 3 lakes studied, Lake Erie is the most populated, which might account for the consistently high counts obtained for each of the 8 samples obtained within this lake as compared to the others. While Lake Superior is the least populated of the 3 lakes, all 5 of our samples within this lake were closer to the shorelines (and thereby closer to the source of pollution) than was the case for Lake Huron, for example. This may explain why the average counts for Lake Superior samples were greater than those for Lake Huron.

Samples 20 and 21 were an anomaly in terms of relative abundance compared to all other samples. The abundance of microdebris, including both coal ash and microplastic particles, may be a result of the convergence of currents in Lake Erie. Annual mean current modeling suggest that currents in Lake Erie are pushed southward along the shoreline (Beletsky et al., 1999). These two samples were collected in the area of converging currents, are in close proximity to several coal burning power plants (Stamper et al., 2012) and are directly downstream from the cities of Detroit, MI, Cleveland, OH and Erie, PA, (Fig. 1).

5. Conclusion

This study aimed to investigate the presence of plastic pollution in the Laurentian Great Lakes ecosystem. In July 2012 a total of 21 samples were collected in three of the five Great Lakes, with overall counts varying from 0 to over 450,000 plastic particles per square kilometer yielding an average count density of $43,157 \pm 115,519$ particles/km².

SEM/EDS analyses of all particles <1 mm differentiated microplastics, including multi-colored plastic spheres, from other materials such as coal ash. Based on dense urban populations adjacent to the lakes that employ combined sewage overflow, and the convergence of lake currents near our sample sites, we believe the microplastic spheres may be microbeads used in consumer product applications, such as those used in facial cleansers. Though sandblasting media may release microplastic particles to the environment, their negative buoyancy in freshwater likely eliminates them as a drifting pollutant. Our study supports the work of Fendall and Sewell (2009), which suggested that the average consumer may be directly releasing microplastics of a size suitable for ingestion by marine organisms without having degraded to become that size. Microbeads are microplastic by design and have similar consequences in the marine environment.

The presence of significant amounts of coal ash and coal fly ash in our samples from the Great Lakes confirms the importance to conduct elemental analysis (SEM/EDS) or chemical analysis (FT-IR) of debris to avoid misidentification. Understanding the type and abundance of microplastics in near shore environments will assist efforts to identify and mitigate sources of plastic marine pollution.

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References

- Andrady, A.L., 2003. Plastics in the environment. In: Andrady, A.L. (Ed.), *Plastics in the Environment*. John Wiley & Sons, New Jersey, NJ, p. 762.
- Astudillo, J.C., Bravo, M., Dumont, C.P., Thiel, M., 2009. Detached aquaculture buoys in the SE Pacific – a potential dispersal vehicle for associated organisms. *Aquatic Biology* 5, 219–231.
- Barnes, D.K.A., Fraser, K.P.P., 2003. Rafting of five phyla on man-made flotsam in the Southern Ocean. *Marine Ecology Progress Series* 262, 289–291.
- Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* 364, 1985–1998.
- Beletsky, D., Saylor, J.H., Schwab, D.J., 1999. Mean circulation in the Great Lakes. *Journal of Great Lakes Research* 25, 78–93.
- Bravo, M., Astudillo, J.C., Lancellotti, D., Luna-Jorquera, G., Valdivia, N., Thiel, M., 2011. Rafting on abiotic substrata: properties of floating items and their influence on community succession. *Marine Ecology Progress Series* 439, 1–17.
- Browne, M.A., Galloway, T.S., Thompson, R.C., 2010. Spatial patterns of plastic debris along estuarine shorelines. *Environmental Science and Technology* 44, 3404–3409.
- Browne, M.A., Crump, P., Niven, S.J., Teuton, E., Tonkin, A., Galloway, T., Thompson, R.C., 2011. Accumulation of microplastic on shorelines worldwide: sources and sinks. *Environmental Science and Technology* 45, 9175–9179.
- Carpenter, E.J., Smith, K.L., 1972. Plastics on the Sargasso sea surface. *Science* 175, 240–241.
- Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: a review. *Marine Pollution Bulletin* 62, 2588–2597.
- Colton, J.B., Knapp, F.D., Burns, B.R., 1974. Plastic particles in surface waters of the northwestern Atlantic. *Science* 185, 491–497.
- Convention on Biological Diversity (CBD), 2012. Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF (2012). *Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions*, Montreal, Technical Series No. 67. <http://www.cbd.int/doc/publications/cbd-ts-67-en.pdf>, Retrieved 12 November 2012.
- Day, R.H., Shaw, D.G., Ignell, S.E., 1990. The quantitative distribution and characteristics of neuston plastic in the North Pacific Ocean, 1984–1988. In: Shomura, R.S., Godfrey, M.L. (Eds.), *Proceedings of the Second International Conference on Marine Debris*, April 2–7, 1989, Honolulu, Hawaii. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS, NOAA-TM-NMFS-SWFC-154, pp. 247–266.
- Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin* 44, 842–852.
- Dubaish, F., Liebezeit, G., 2013. Suspended microplastics and black carbon particles in the Jade System, Southern North Sea. *Water Air Soil Pollution* 224, 1352. <http://dx.doi.org/10.1007/s11270-012-1352-9>.
- EPA, 2007. Report to Congress: Combined Sewer Overflows to the Lake Michigan Basin. EPA-833-R-07-007.
- Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., Hafner, J., Zellers, A., Rifman, S., 2013. Plastic pollution in the South Pacific subtropical gyre. *Marine Pollution Bulletin* 68, 71–76.
- Fendall, L.S., Sewell, M.A., 2009. Contributing to marine pollution by washing your face: microplastics in facial cleansers. *Marine Pollution Bulletin* 58, 1225–1228.
- Gregory, M.R., 1996. Plastic ‘Scrubbers’ in Hand Cleansers: a further (and minor) source for Marine Pollution Identified. *Marine Pollution Bulletin* 32, 867–871.
- Gregory, M.R., Ryan, P.G., 1997. Pelagic plastics and other seaborne persistent synthetic debris: a review of Southern Hemisphere perspectives. In: Coe, J.M., Rogers, D.B. (Eds.), *Marine Debris – Sources, Impacts and Solutions*. Springer-Verlag, New York, pp. 49–66.
- Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings – entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* 364, 2013–2025.
- Laist, D.W., 1987. Overview of the biological effects of lost and discarded plastic debris in the marine environment. *Marine Pollution Bulletin* 18, 319–326.
- Law, K.L., Morét-Ferguson, S., Maximenko, N., Proskurowski, G., Peacock, E.E., Hafner, J., Reddy, C.M., 2010. Plastic accumulation in the North Atlantic Subtropical Gyre. *Science* 329, 1185–1188.
- Mato, Y., Isobe, T., Takada, H., Kanehiro, H., Ohtake, C., Kaminuma, T., 2001. Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. *Environmental Science and Technology* 35, 318–324.
- Moore, C.J., Moore, S.L., Leecaster, M.K., Weisberg, S.B., 2001. A comparison of plastic and plankton in the North Pacific Central Gyre. *Marine Pollution Bulletin* 42, 1297–1300.
- Rios, L.M., Joes, P.R., Moore, C., Narayan, U.V., 2010. Quantification of persistent organic pollutants adsorbed on plastic debris from the Northern Pacific Gyre’s “eastern garbage patch”. *Journal of Environmental Monitoring* 12, 2226–2236.
- Ryan, P.G., Moore, C.J., van Franeker, J.A., Moloney, C.L., 2009. Monitoring the abundance of plastic debris in the marine environment. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* 364, 1999–2012.
- Saruhan, V., Gul, I., Aydin, I., 2010. The effects of sewage sludge used as fertilizer on argonomic and chemical features of bird’s foot trefoil and soil pollution. *Sci. Res. Essays* 5, 2567–2573.
- Stamper, V., Copeland, C., Williams, M., 2012. Poisoning the Great Lakes: Mercury Emissions from Coal-fired Power Plants in the Great Lakes Region. National Resource Defense Council report. <http://www.nrdc.org/air/files/poisoning-the-great-lakes.pdf>.
- STS Analytical Testing Laboratory, 6 Executive Park Dr., North Billerica, MA 01862. 2013. <http://www.atl.semtechsolutions.com/node/84/coal-and-fly-ash-analysis>.
- Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., McGonigle, D., Russell, A.E., 2004. Lost at Sea: Where is all the plastic? *Science* 304, 838.
- Teuten, E.L., Rowland, S.J., Galloway, T.S., Thompson, R.C., 2007. Potential for plastics to transport hydrophobic contaminants. *Environmental Science and Technology* 41, 7759–7764.
- Teuten, E.L., Saquing, J.M., Knappe, D.R.U., Barlaz, M.A., Jonsson, S., Björn, A., Rowland, S.J., Thompson, R.C., Galloway, T.S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P.H., Tana, T.S., Prudente, M., Boonyatumanond, R., Zakaria, M.P., Akkhavong, K., Ogata, Y., Hirai, H., Iwasa, S., Mizukawa, K., Hagino, Y., Imamura, A., Saha, M., Takada, H., 2009. Transport and release of chemicals from plastics to the environment and to wildlife. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* 364, 2027–2045.
- Thiel, M., Hinojosa, I.A., Miranda, Pantoja, J., Rivadeneira, M.M., Vasquez, N., 2013. Anthropogenic marine debris in the coastal environment: a multi-year comparison between coastal waters and local beaches. *Marine Pollution Bulletin* 71, 307–316.
- Van Franeker, J.A., Blaize, C., Danielsen, J., Fairclough, K., Gollan, J., Guse, N., Hansen, P.L., Heubeck, M., Jensen, J.K., Le Guillou, G., Olsen, B., Olsen, K.O., Pedersen, J., Stienen, E.W.M., Turner, D.M., 2011. Monitoring plastic ingestion by the

- northern fulmar *Fulmarus glacialis* in the North Sea. Environmental Pollution 159, 2609–2615.
- Webb, H., Crawford, R., Sawabe, T., Ivanova, E., 2009. Poly(ethylene terephthalate) polymer surfaces as a substrate for bacterial attachment and biofilm formation. Microbes and Environments 24, 39–42.
- Zbyszewski, M., Corcoran, P., 2011. Distribution and degradation of fresh water plastic particles along the beaches of Lake Huron, Canada. Water, Air and Soil Pollution 220, 365–372.
- Zitko, V., Hanlon, M., 1991. Another source of pollution by plastics: skin cleansers with plastic scrubbers. Marine Pollution Bulletin 22, 41–42.